Internal Tide Generation by Steep Topography

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LONGTERM GOALS

Our interests are in oceanic processes that contribute to stirring and mixing in order to understand their impact on larger scales. This includes phenomena ranging from the mesoscale (10-100 km) to the microscale (1 cm). Of particular interest is how these various processes interact to produce turbulence and mixing with a particular focus on internal waves.

OBJECTIVES

E. Kunze's recent focus has been on how meso- and finescale flow fields interact with complex topography such as seamounts, canyons, ridges and the continental slope (Kunze and Llewellyn Smith 2004). A prominent interaction which creates large currents and temperature fluctuations that radiate far from the generation site is that of surface tidal currents with smallscale topography to generate internal waves and turbulence. Internal tide generation is also implicated in contributing to deep-ocean turbulent mixing (Munk and Wunsch 1998). A straightforward theory to handle arbitrary, steep topography is not available, yet these sites appear to be the strongest sources of internal tides.

APPROACH

An alternative physics-based solution method to Baines' (1982) theory has been developed. This linear theory can handle arbitrary 1-D topography on scales larger than the waves' horizontal wavelengths. Its solutions will be compared to recent observations, numerical simulations, weak-topography theory and special-case steep topography.   The solutions' sensitivity to small changes in stratification at the generation site will also be examined as this is often put forward as an explanation for the observation that open-ocean internal tides exhibit strong temporal variability (Rainville and Pinkel 2006). This work represents a means to synthesize observations that Eric Kunze has been involved in collecting over the last several years.

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The solution method uses characteristic coordinates along which signals of frequency ω propagate, $X\pm\pm = \pm x \pm sz$, where the inverse ray path slope $s = N/\sqrt{\omega^2 - f^2}$, to formulate a forced differential equation for the along-ray velocities

$$\frac{\partial U_{\pm}}{\partial X_{\pm}} = \pm\frac{U_0 h_0 z}{4}\frac{\partial^2}{\partial x^2}\left(\frac{1}{h}\right),$$

from which one obtains the baroclinic along-ray velocity by integrating along a ray path

$$U_{\pm} = \pm\frac{U_0 h_0}{4}\int_{X_{\pm}}(z+\frac{h}{2})\frac{\partial^2}{\partial x^2}\left(\frac{1}{h}\right)dX_{\pm}.$$

As illustrated in Fig. 1, each point $(x0, z0)$ in space is fed by four rays $X\pm\pm$. Each ray originates at the edge of the domain, where internal tide velocities are assumed zero to set the boundary condition, then is integrated through multiple surface and bottom reflections until arriving at $(x0, z0)$. This solution method is novel and therefore requires validation against observations and established theories.
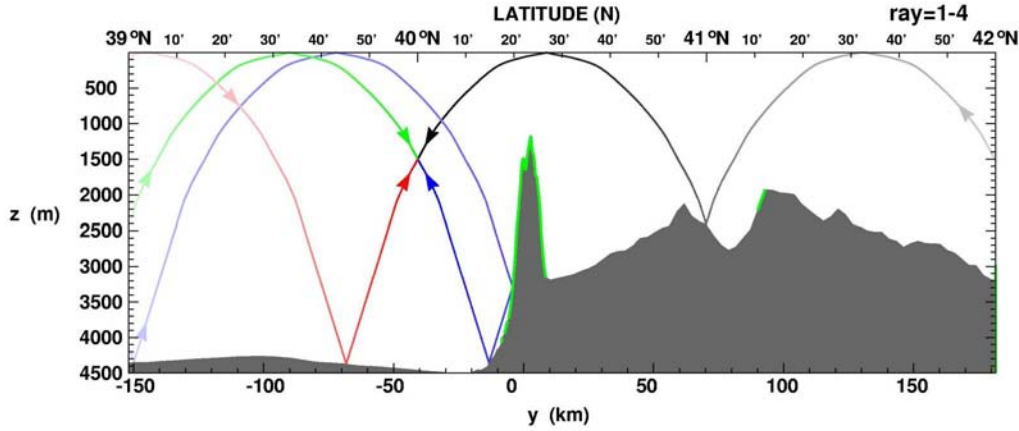
Figure 1: Illustration of new solution method for a section across Mendocino Escarpment. Supercritical topography is indicated in green. Each point is influenced by information travelling along 4 rays that are assumed to enter the domain with zero alongray velocities (U± = 0). The complete solution is obtained by integrating along the rays, then summing the 4 solutions.

WORK COMPLETED

The numerical code developed to solve the analytic problem for arbitrary 1-D bathymetry and stratification is being compared to the predictions analytic theory and field observations for debugging purposes. Two limitations to the method outlined above have appeared as a result:

(i) the ray-path method cannot handle trenches with supercritical walls; ray paths become trapped and focussed toward the bottom in such topography;

(ii) stratification lengthscales have to be longer than the resulting internal wave scales to satisfy the WKB approximation.

These problems are not a concern for the ridge bathymetries and data sets we are considering. Preliminary comparisons of the method with data from HOME Survey measurements appear in Nash *et al*. (2006). Eric Kunze also co-wrote an article reviewing our understanding of internal tide generation (Garrett and Kunze 2007) and used funds from this program to reduce costs of fieldwork off Point Sur, CA for the AESOP DRI this summer where he obtained full-depth profile time-series of turbulent microstructure at 6 stations.

RESULTS

While preliminary comparison of the new solution method and observations across Mendocino Escarpment is encouraging (Fig. 2), comparisons against Bell's (1975) analytic theory for small-amplitude subcritical-slope topography uncovered a number of bugs which been corrected (Fig. 3). Comparison with the knife-edge solution of St. Laurent *et al.* (2003) revealed large discrepancies which remain to be diagnosed. Pascale Lelong is implementing a numerical model which solves the 3-D nonlinear Boussinesq equations in domains with variable bathymetry for the purpose of validating the theoretical solution approach described above. Direct numerical solution of the equations of motion may also shed further insight, especially in regions with sharp or 3-D topography.
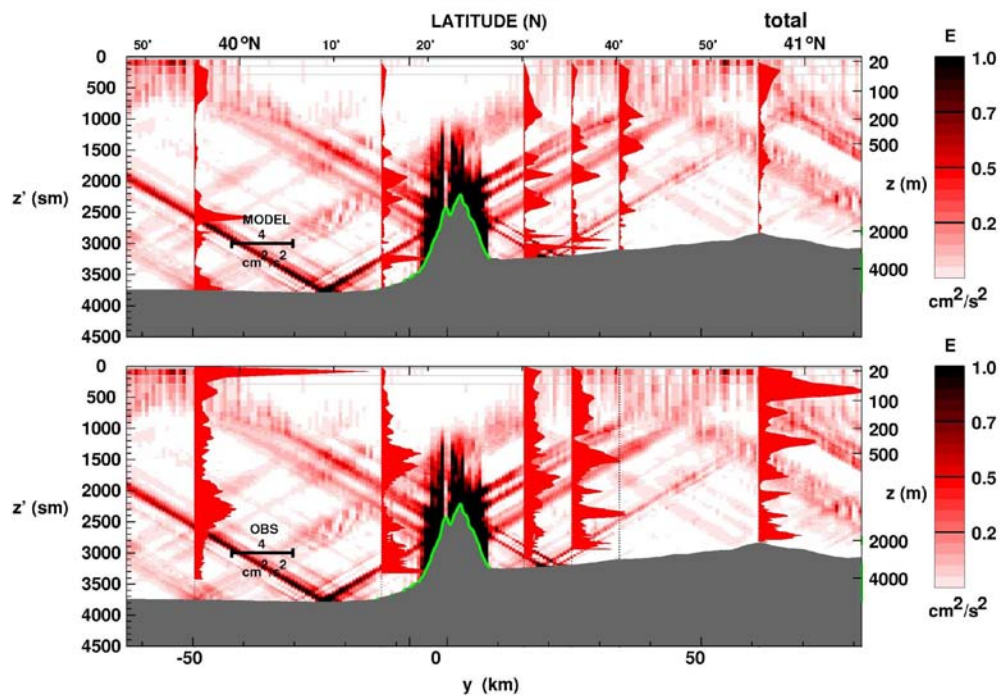
Figure 2: Preliminary comparison between semidiurnal energy profiles (red) from the new solution method (upper panel) and observations across Mendocino Escarpment (lower panel). The background red shading shows the model solution everywhere in both panels.
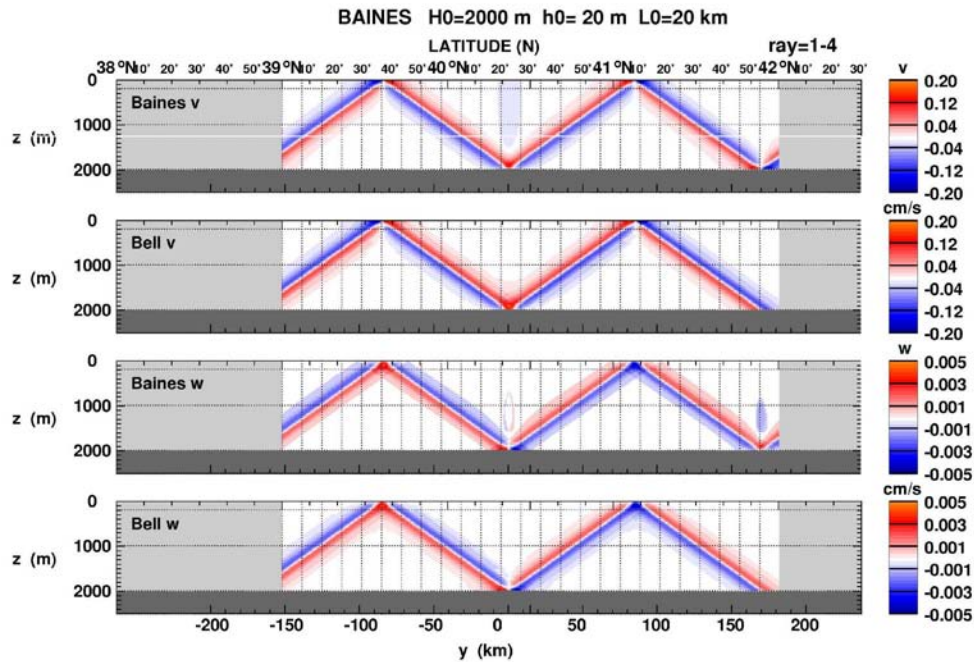
Figure 3: Comparison of horizontal velocity v and vertical velocity w from the new solution method for Baines and the Bell (1975) analytic solution for a small-amplitude gently-sloped ridge.

IMPACT/APPLICATION

As well as synthesizing recent observations, this work hopes to provide a more straightforward tool for comparing observations of internal tide generation with theory than has previously been available, providing predictions for cruise planning and operational applications. Theory to date has either been for small-amplitude topography or focused on case studies for steep topography described by analytic functions so there is a need for a more general approach. As pointed out in Garrett and Kunze (2007), the full problem for two-dimensional steep finite-amplitude topography remains.

RELATED PROJECTS

This work will help synthesize recent observations at Mendocino Escarpment (Althaus *et al*. 2003), in Monterey Submarine Canyon (Kunze *et al*. 2002; Lien and Gregg 2002), the Virginia continental slope (Nash *et al*. 2004), the Oregon continental slope (Nash *et al*. submitted), along the Hawaiian Ridge (Rudnick *et al*. 2003; Lee *et al*. 2006; Nash *et al*. 2006) and in global LADCP/CTD data sets (Kunze *et al*. 2006) by providing a conceptual framework for the interpretation of these data sets.

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